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Influence of four Humic Extracts on the Agronomic Parameters of Rice Plants

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In Côte d'Ivoire, the high dependence on rice imports is exacerbated by low national productivity, primarily due to soil degradation. The use of humic extracts (HE) derived from animal manure represents a sustainable alternative for improving soil fertility. However, their effectiveness varies depending on the source and application dose, necessitating a comparative evaluation to optimize their use in rice farming. This study aimed to assess the influence of the source (cow, chicken, pig, rabbit) and the application dose (D1: 1 %, D2: 2.5 %, D3: 5 %) of humic extracts on the agronomic parameters and yield of rice (Oryza sativa). The experiment was conducted following a randomized complete block design with three replications. Twelve treatments combining four HE sources and three doses were compared to a control receiving mineral fertilization (NPK + Urea). The measured parameters included plant height, number of tillers, number of full and empty grains per panicle, 1000-grain weight, and yield. The application of humic extracts significantly improved rice growth and yield compared to mineral control. Extracts from rabbit (2.5 %) and pig (2.5 %) manure increased plant height by 12.2 % and 10.75 %, respectively. The 5 % pig extract induced the highest increase in the number of tillers (+ 45 %). All HE treatments increased the number of full grains per panicle (up to +35.6 %) and reduced the number of empty grains, with a notable 53 % decrease observed for the pig and rabbit manure extracts at 2.5 %. The 1000-grain weight was unaffected by any treatment. Grain yield showed a significant increase, reaching a maximum of 12.13 t / ha with the 2.5 % pig extract. Humic extracts derived from local animal manure, especially those from pigs, represent a highly promising solution for sustainably increasing rice yields in Côte d'Ivoire.
Keywords: *Oryza sativa*, humic extract, animal manure, soil fertility, agronomic yield, sustainable agriculture, organic amendment.

INTRODUCTION

Rice (*Oryza sativa* L.) is a cornerstone of food security for more than half of the global population. In Sub-Saharan Africa, particularly in West Africa, this cereal has shifted from a luxury crop to a strategic staple food, with demand growing faster than any other major food commodity (Seck et al., 2012). Côte d'Ivoire perfectly exemplifies this trend. With per capita consumption soaring over the last few decades to exceed 80 kg per year, the country faces strong domestic demand coupled with insufficient local production. This chronic deficit forces the country to rely on massive imports, which amounted to nearly 1.5 million tons in 2023, accounting for about 50 % of national needs, making Côte d'Ivoire one of the largest rice importers on the continent (Yao et al., 2025). This dependency not only weakens the trade balance but also exposes the country's food security to fluctuations in international markets. One of the primary causes of this low rice productivity is the progressive and widespread degradation of soil fertility. Decades of intensive agricultural practices, often characterized by continuous monoculture, minimal or nonexistent organic matter restitution, and nutritional imbalances, have led to severe soil depletion (Bationo et al., 2018). While mineral fertilizers are essential, they alone cannot reverse this trend, and their improper use may even exacerbate issues like soil acidification (Vanlauwe et al., 2015). In light of this, adopting sustainable intensification strategies, based on integrated soil

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fertility management, has become a top priority for agricultural research. Over the past two decades, scientific research has extensively demonstrated that humic substances positively influence plant growth and development through various physiological and metabolic mechanisms. As biostimulants, they do not directly provide nutrients but enhance the efficiency of their absorption and assimilation by plants (Du Jardin, 2015). They have been shown to modify root system architecture, particularly by stimulating the growth of lateral roots and root hairs, thereby increasing the soil exploration surface (Canellas & Olivares, 2014). Moreover, they can chelate micronutrient metals, keeping them in an assimilable form, and improve cell membrane permeability, facilitating nutrient uptake (Nardi et al., 2021). These combined effects allow plants to better utilize soil resources and better withstand abiotic stresses, such as drought or salinity (Olivares et al., 2017). However, the agronomic efficacy of humic substances is far from universal. It critically depends on numerous factors, including the nature and maturity of the organic matter source, the extraction processes, the concentration of the applied solution, the target plant species, and pedoclimatic conditions (Jindo et al., 2020). Manure from different animals (cattle, poultry, pigs, etc.) has varying biochemical compositions, which directly influence the quality and bioactivity of the derived humic extracts. While the potential of organic amendments is recognized, studies focusing on a rigorous comparative evaluation of humic extracts from various local animal sources and their optimal doses for rice farming remain scarce. This lack of specific data is a major barrier to developing precise technical recommendations for Ivorian farmers. It is within this context that the present study was conducted, aiming to evaluate the influence of humic extract origin and application dose on the agronomic parameters and yield of rice (*Oryza sativa*) in Côte d'Ivoire.

MATERIALS AND METHODS

***Plant material*:** The plant material used consisted of rice seeds of the C26 variety, provided by the Agency for the Development of the Rice Sector (ADERIZ) in Abidjan. The selection of this variety was due to its tolerance to lodging, drought, and its good taste qualities. It is characterized by long grains and adapts well to various cropping systems (CORAF, 2018).

***Fertilizers used*:** The fertilizers used included four types of humic extracts derived from composted manures of pig, cow, rabbit, and chicken (Figure 1), as well as NPK (12-22-22) and Urea 46 %. g Urea).

***Experimentation*:** The experiment started with the establishment of 39 subplots. These subplots were created in pits measuring 50 cm deep, 2 m long, and 1 m wide, simulating artificial lowlands. Each pit was lined with a black plastic sheet to retain irrigation water. The pits were then filled to two-thirds of their volume with surface soil from the humic horizon (Figure 2a). The experimental design used was a randomized complete block design with three repetitions. A spacing of 1 meter was maintained between the pits (subplots) within each experimental block. The blocks themselves were separated by a 1.5-meter gap. Two main factors were studied during this trial: the source of the humic extract, with four variants (from cow, chicken, pig, and rabbit manure), and the application dose of these extracts, tested at three levels (1 %, 2.5 %, and 5 %). A single control treatment receiving chemical fertilizer (40 g NPK + 30 g Urea) complemented the twelve (12) factorial combinations at half the dose of chemical fertilizer. Thus, the total number of treatments amounted to thirteen (13) distinct treatments per block. Once the subplots were prepared, healthy 15-day-old rice seedlings were transplanted. Each subplot received 36 seedlings, spaced 20 cm apart both between rows and plants. The crops received regular irrigation with water to maintain an adequate substrate moisture level (Figure 2b). Urea was applied two weeks after transplanting. Additionally, a curative insecticide treatment formulated with Lambda-cyhalothrin (15 g/L) and Acetamiprid (20 g/L) was applied in the presence of insect infestations.

Figure 1. Appearance of the humic extract
EHB: humic extract from cow dung; EHF: humic extract from chicken; EHC: humic extract from rabbit droppings; EHP: humic extract from pig droppings.

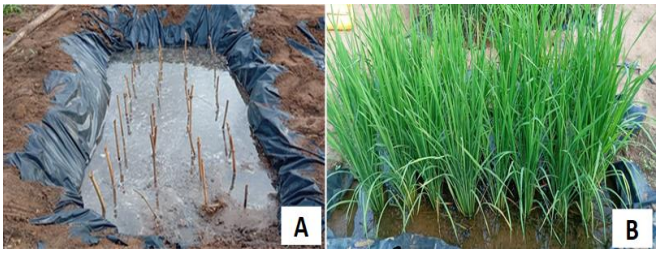

Figure 2. View of a subplot.
(A) Before transplanting; (B) After transplanting)

Agronomic parameters measurement

***Growth parameter*:** Plant height was measured using a graduated tape measure and recorded in centimeters. The

number of tillers was determined by counting the number of stems on each rice plant. The average number of tillers and average height were calculated using the following formulas:

$$\text{Tmoy} = \frac{Sum\ of\ the\ Talles\ of\ the\ plants}{total\ number\ of\ plants}$$

$$\text{Hmoy (cm)} = \frac{\text{Sum of Plant Heights}}{total\ number\ of\ plants}$$

With Tmoy: average number of talles, Hmoy: average height

***Yield Parameter*:** The number of grains per panicle, the number of empty grains, the weight of 1000 grains, and the yield were evaluated. The yield was determined by the following formula:

$$R = \frac{\text{mass of the elementary surface}}{\text{area of the subpot}} \times 10 - 2$$

With R: yield

***Statistical analysis methods*:** All collected data were entered into an Excel table. Graphs were created for illustrative purposes. For comparative analysis, data normality and homogeneity were checked using Shapiro-Wilk and Levene's tests. If these conditions were not met, the Kruskal-Wallis test was performed. Otherwise, the Newman-Keuls multiple comparison test was used to compare means when one-way ANOVA (ANOVA 1) revealed significant differences. Statistical analyses were performed using the XLSTAT software version 2016, and tests were conducted at a 5 % probability threshold.

RESULTS

***Effect of humic extracts on rice plant height*:** The analysis of plant height revealed highly significant differences between the treatments (p = 0.001). Overall, the application of humic extracts resulted in increased plant height compared to the control, which measured 90.45 cm. However, this increase varied considerably depending on the type of extract and the applied dose. The most notable performances in terms of height were observed with the D2 doses of the EHC (101.48 cm) and EHP (100.17 cm) extracts. The D1 dose of the EHF extract (98.99 cm) also showed good results. On the other hand, the treatments with lower heights were those of the D1 and D2 doses of the EHB extract, with respective values of 89.7 cm and 94.63 cm. The D1 dose of the EHC extract (95.59 cm), the D3 dose of the EHP extract (93.49 cm), and the control (90.45 cm) also exhibited relatively lower heights.

***Effect of humic extracts on the number of tillers per rice plant*:** The effect of humic extracts on the number of tillers per plant showed significant variability (p = 0.001). An outstanding performance was observed with the D3 dose of the EHP extract, which resulted in an average of 19 tillers per plant, significantly higher than the other treatments, forming a distinct group (A) according to the Newman-Keuls post-hoc test. The second group (B), which showed significantly more tillers than the control (13.12 tillers), included the D2 dose of the EHF extract (15.33 tillers), the D2 dose of the EHC extract (15.29 tillers), and the D1 dose of the EHF extract (14.95 tillers). All other treatments, including the control, were classified into the lower group (C).

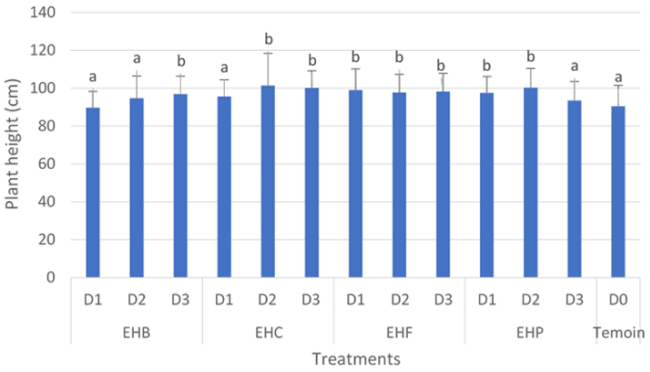

Figure 3. Effect of humic extracts on rice plant height.
The means of plant height followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHB: humic extract from cow dung; EHC: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

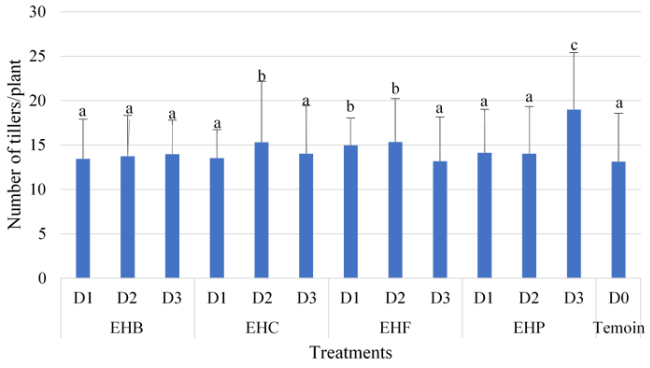

Figure 4. Effect of humic extracts on the number of tillers per rice plant.
The means of the number of tillers per plant followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHB: humic extract from cow dung; EHC: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

***Effect of humic extracts on the number of full grains per rice panicle*:** The application of humic extracts had a very strong and positive impact on the number of full grains per panicle (p = 0.0001). All humic extract treatments resulted in a significant increase in this number compared to the control, which recorded the lowest value of 141 grains and was placed in the last statistical group (C). In contrast, the top group (A), which includes the most effective treatments for this parameter, consisted of the following results: EHB-D2 with 185.18 grains, EHC-D3 with 187.87 grains, EHF-D1 with 186.58 grains, EHP-D1 with 191.95 grains, and EHP-D3 with

182.04 grains. The other treatments (EHB-D1, EHB-D3, EHC-D1, EHC-D2, EHF-D2, EHF-D3, and EHP-D2) formed the second group (B), which was also significantly superior to the control group.

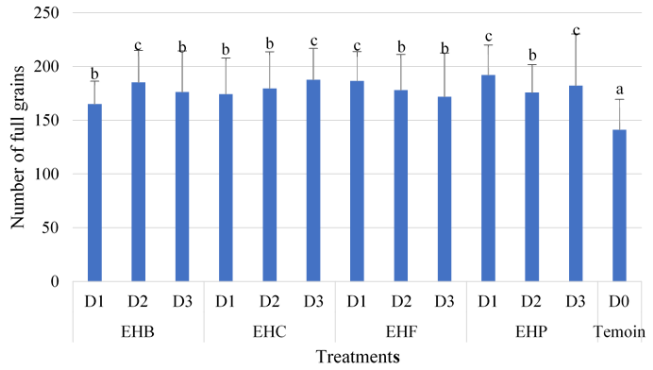

Figure 5. Effect of humic extracts on the number of full grains per rice panicle.

The means of the number of full grains per panicle followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHB: humic extract from cow dung; EHC: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

***Effect of humic extracts on the number of empty grains per rice panicle*:** Unlike the full grains, the number of empty grains per panicle showed a significant reduction due to the application of humic extracts ($p = 0.034$). The control treatment (D0) had the highest number of empty grains with 34 grains, placing it in the least effective group (D). In contrast, the treatments EHC-D2 (18.33 empty grains), EHF-D2 (20.63 empty grains), and EHP-D2 (16.04 empty grains) were classified into the top group (A), representing the treatments that most improved grain filling. The treatments EHB-D2, EHB-D3, EHC-D1, EHF-D1, and EHP-D1 formed the second group (B), with an average of 25 empty grains. The third group consisted of the following treatments: EHB-D1 (28.47 empty grains), EHC-D3 (27.29 empty grains), and EHF-D3 (27.47 empty grains).

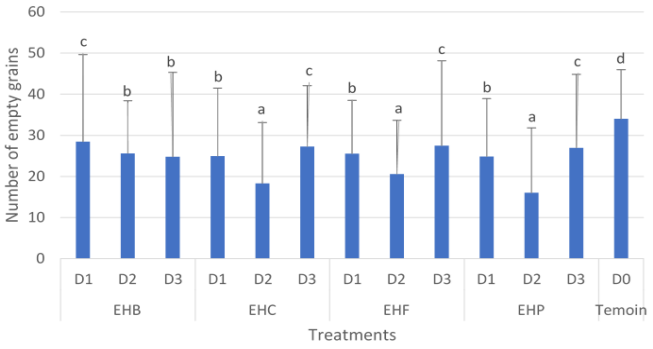

Figure 6. Effect of humic extracts on the number of empty grains per rice panicle.

The means of the number of empty grains per panicle followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHD: humic extract from cow dung; EHC: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

***Influence of humic extracts on 1000 grain weight*:** Unlike the other yield parameters, the 1000-grain weight showed no significant variation ($p = 0.244$) due to the application of different humic extracts and their doses. The measured values remained close to the control (21.56 g), ranging from 20.08 g for the EHP-D3 treatment to 23.40 g for the EHC-D1 treatment. Furthermore, the Newman-Keuls test did not show any statistically significant differences between the various treatments. This indicates that during this experiment, the humic substances analyzed mainly influenced the number of grains produced rather than their individual weight.

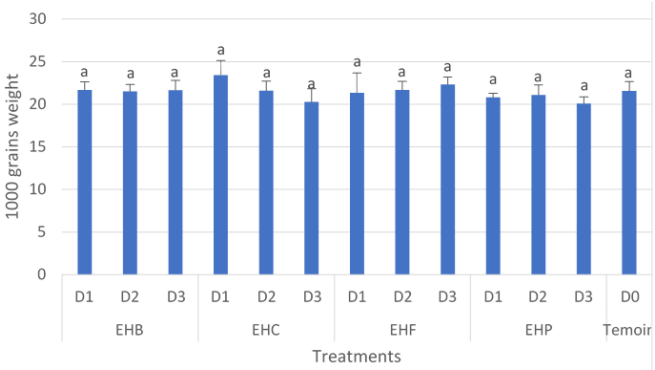

Figure 7. Influence of humic extracts on the 1000-grain weight of rice.

The means of the 1000-grain weight followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHB: humic extract from cow dung; EHR: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

***Effect of humic extracts on grain yield*:** The grain yield (g/m^2) was significantly impacted by the different treatments applied ($p = 0.027$). All humic extract treatments surpassed the yield of the control, which was 707.34 g/m^2, thus logically placing it in the least productive category. The Newman-Keuls test revealed the exceptional performance of the D2 dose of the EHP extract, reaching 12.13 t / ha, which placed it alone in group A. The second group, consisting of effective treatments, included the D2 (10.68 t / ha) and D3 (9.52 t / ha) doses of the EHB extract, as well as the D2 (11.06 t / ha) and D3 (9.06 t / ha) doses of the EHC extract, the D2 (10.03 t / ha) dose of the EHF extract, and the D1 (10.05 t / ha) dose of the EHP extract. The third group included the following treatments: EHB-D1 (8.83 t / ha), EHC-D1 (9.06 t / ha), EHF-

D1 (9.76 t / ha), EHF-D3 (10.03 t / ha), and EHP-D3 (9.17 t / ha).

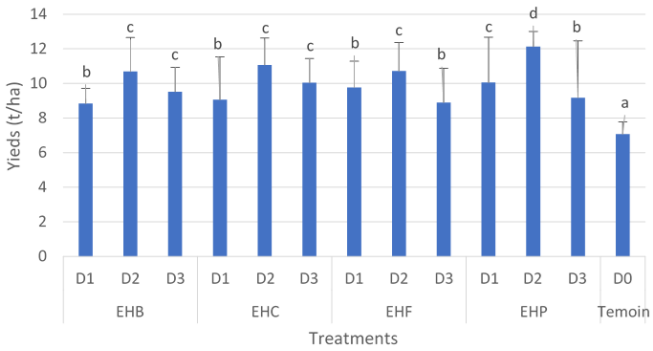

Figure 8. Influence of humic extracts on rice grain yield. The means of the grain yield followed by the same letter show no significant difference at the 5% threshold (Newman-Keuls test); error bars represent standard errors; D0: control; D1: 1%; D2: 2.5%; D3: 5%; EHB: humic extract from cow dung; EHR: humic extract from rabbit manure; EHF: humic extract from chicken manure; EHP: humic extract from pig manure.

DISCUSSION

The results of this study confirm the significant agronomic interest of humic extracts (HE) derived from animal manure for promoting the growth and yield of rice crops. Analysis of the vegetative growth parameters indeed revealed notable improvements in the plants treated with different HE compared to the control. Significant gains in plant height and the average number of tillers were observed with specific treatments, particularly those based on pig slurry extracts (EHP). These beneficial effects were clearly manifested in the yield components. The number of full grains per panicle was consistently higher in the plants treated with HE compared to the control. Simultaneously, the number of empty grains decreased. As a result, grain yield significantly increased for several HE treatments, far surpassing that of the control group. The efficacy of humic substances can be explained by various mechanisms of action. These include hormonal effects and a substantial improvement in mineral nutrition (Kulikova et al., 2005; Diego et al., 2013). The hormonal activity, often attributed to an auxin-like effect (AIA), is believed to promote root cell elongation via the activation of the H+ATPase membrane pump (Sze et al., 1999). These observations on rice support earlier findings that highlighted the positive effect of humic substances (HS) on a wide range of other crops. Growth improvements have been reported in wheat (Baqir et al., 2019 ; Zeboon, 2018) and Italian ryegrass (Laila et al., 2017). Recent studies confirm these benefits on yield and quality in groundnut (Chaitra et al., 2024), as well as on aesthetic parameters and floral longevity (Al-Bayati et al., 2023), demonstrating the wide-ranging impact of these compounds. Beyond these physiological effects, the intrinsic mineral composition of the HE used to seem to play a crucial role. For example, the EHF extract, rich in organic matter (OM), carbon (C), nitrogen (N), and potassium (K), showed good growth results. The EHC and EHP extracts, with high concentrations of OM, C, and phosphorus (P), also yielded satisfactory results. The most significant results from EHP and EHF extracts were correlated with their high content of OM, C, and specific nutrients, suggesting a synergy between the biostimulant effects of HS and the direct nutrient contribution. Previous studies, such as those by Sarkar and Mukhopadhyay (1990), report increases in rice yields ranging from 19.3 to 49.1% following foliar application of potassium nitrate. Abdi (2015) demonstrated an 8% increase in protein content and a 40% increase in wheat yield through foliar application of urea and KCl during key growth stages. Srivastava *et al.* (2013) also observed a 13.8% yield improvement in rice and a 6.2% improvement in wheat following foliar application of zinc. Finally, Mahmoodi *et al.* (2020) achieved significant increases in rice yield with a foliar NPK (7-7-7) fertilizer enriched with micronutrients, showing results such as a 7% increase in height, 21% in size, 13% in chlorophyll, 22% in filled grains, and an 11.16% increase in yield, with no impact on 1000-grain weight. These studies confirm the efficacy of direct nutrient applications through foliar treatments. The beneficial effect of these treatments, whether derived from HE or mineral fertilizers, relies on the provision of essential elements such as N, P, and K, crucial for plant vital processes. HE, in addition to providing some of these nutrients, contributes OM and carbon-based compounds. These can improve the nutrient absorption efficiency of associated mineral nutrients, particularly through chelation, facilitating their foliar assimilation. Thus, the benefits of humic extracts arise from a combination of direct nutrient supply and specific biostimulant effects.

***Conclusion*:** At the end of this study, the results showed that humic extracts differently influence the agronomic parameters of rice, depending on their origin (and thus their physico-chemical composition) and the applied dose. The EHP extract at the D2 dose (2.5%) proved to be the most promising for improving rice yield. However, it is important to note that a high dose of an extract (5%) may positively influence one parameter (such as the number of tillers) while drastically reducing the final yield. These results highlight the importance of optimizing both the type of extract and its concentration to maximize the agronomic benefits in rice farming. Further research could explore the underlying physiological mechanisms behind these differential responses.

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A. Khan, K. Hussnain prepared the draft; K. Mehmood, M. M. Khan reviewed and finalized the draft.

***Conflict of interest*:** The authors declare no conflict of interest.

***Ethical statement*:** This article does not contain any studies which require ethics committee approval.

***Availability of data and material*:** The data is available with the corresponding author which can be made available on request.

***Consent for publication*:** All authors submitted consent to publish this research article in JGIAS.

***SDGs addressed*:** No poverty; zero hunger; good health and well-being.

***Policy referred*:** National Policies of Côte d'Ivoire; International and Regional Frameworks.

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REFERENCES

Abdi, M. (2015). Influence of KCl and urea spraying on quality and quantity of wheat cv. Sardari under rainfed conditions. *Journal Agroecological*, *10*, 33-34.

Al-Bayati, M. Y. I., Sattar, A. G., & Al-Fatlawi, K. A. (2023). Response of *Rosa pygmaea* to humic and fulvic acids under exposed environment conditions. *Conference Series: Earth and Environmental Science*, *1252*, 012106.

Baqir, H. A., & Zeboon, N. H. (2019). Response of some wheat growth traits for foliar spraying with humic and glutamic acid. *Iraqi Journal of Agricultural Sciences*, *50*, 1455-1464.

Bationo, A., Ngaradoum, D., Youl, S., Lompo, F., & Fening, J. O. (2018). A review of the soil fertility in West Africa. In *Fighting rural poverty in developing countries* (pp. 517-548). Springer.

Canellas, L. P., & Olivares, F. L. (2014). Physiological responses of plants to humic substances. *Soil Science and Plant Nutrition*, *60*, 147-158.

Chaitra, P., Math, K. K., Ragini, S. P., Gitanjli, R., Gowthamchand, N. J., & Gargi, S. (2024). Effect of humic acid from vermicompost and commercial source on growth, yield and quality of groundnut (*Arachis hypogea* L.). *Environment and Ecology*, *42*, 77-83.

CORAF. (2018). *Regional catalogue of plant species and varieties* (Vol. 2). ECOWAS-UEMOA-CILSS.

Diego, P., Ornella, F., Andrea, E., Adele, M., & Serenella, N. (2013). Isopentenyladenosine and cytokinin-like activity of different humic substances. *Journal of Geochemical Exploration*, *129*, 70-75.

Du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, *196*, 3-14.

Jindo, K., Martim, S. A., Navarro, E. C., Pérez-Alfocea, F., Hernandez, T., Garcia, C., & Aguiar, N. O. (2020). Root-promoting activity of humic substances: A review. *Agronomy*, *10*, 885.

Kulikova, N. A., Stepanova, E. V., & Koroleva, O. V. (2005). Mitigating activity of humic substances: Direct influence on biota. In I. B. Perminova, K. Hatfield, & N. Hertkorn (Eds.), *Use of humic substances to remediate polluted environments: From theory to practice* (pp. 285-309). Springer.

Laila, K., Min, G. K., Woe-Yeon, K., Jong-Rok, J., & Joon-Yung, C. (2017). Humic acid and synthesized humic mimic promote the growth of Italian ryegrass. *Journal of the Korean Society of Grassland and Forage Science*, *37*, 242-247.

Mahmoodi, S., Rahnamaee, S., & Bahar, M. (2020). Effects of foliar application of liquid fertilizer on agronomical and physiological traits of rice (*Oryza sativa* L.). *Acta Agrobotanica*, *73*. https://doi.org/10.5586/aa.7332

Nardi, S., Pizzeghello, D., Muscolo, A., & Vianello, A. (2002). Physiological effects of humic substances on higher plants. *Soil Biology and Biochemistry*, *34*, 1527-1536.

Olivares, F. L., Busato, J. G., & de Paula, A. M. (2017). Bactéries et substances humiques favorisant la croissance des plantes: Promotion des cultures et mécanismes d'action. *Chemical and Biological Technologies in Agriculture*, *4*, 30. https://doi.org/10.1186/s40538-017-0112-x

Sarkar, A. K., & Mukhopadhyay, M. (1990). Response of rice cultivars to post-flowering foliar application of potassium nitrate solution. *Indian Agriculturist*, *34*, 119-122.

Seck, P. A., Diagne, A., Mohanty, S., & Wopereis, M. C. (2012). Crops that feed the world 7: Rice. *Food Security*, *4*, 7-24.

Srivastava, P. C., Bhatt, M., Pachauri, S. P., & Tyagi, A. (2013). Effect of zinc application methods on apparent utilization efficiency of zinc and phosphorus fertilizers under basmati rice-wheat rotation. *Archives of Agronomy and Soil Science*, *60*, 33-48.

Sze, H., Li, X., & Palmgren, M. G. (1999). Energization of plant cell membranes by H^+-pumping ATPases: Regulation and biosynthesis. *Plant Cell*, *11*, 677-689.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., & Sanginga, N. (2015). Integrated soil fertility management: From knowledge to implementation in sub-Saharan Africa. *Advances in Agronomy*, *109*, 1-45.

Yao, I., Beillard, J. M., & Galloway, G. J. (2025). *Report: Grain and feed annual—2025*. Foreign Agricultural Service (FAS), Office of Agricultural Affairs (OAA).

Zeboon, N. H. (2018). Response of growth and yield of *Zea mays* to foliar spraying with humic acid. *International Journal of Agricultural and Statistical Sciences*, *14*, 153-157.